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Fracture toughness investigation of the dynamically vulcanized EPDM/PP/ionomer ternary blends using the *J*-integral via the locus method

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The fracture mechanics investigation of the dynamically vulcanized EPDM and PP/ionomer ternary blends was performed in terms of the *J*-integral by measuring fracture energy via the locus method. The ternary blends consisting of EPDM, PP and ionomer were prepared in a laboratory internal mixer by blending and vulcanizing simultaneously. Vulcanization was performed with dicumyl peroxide (DCP) and the composition of EPDM and PP was fixed at 50/50 by weight. Two kinds of poly(ethylene-co-methacrylic acid) (EMA) ionomers were used. The *J*-integral values at crack initiation, J_c, of the dynamically vulcanized EPDM and PP/EMA ionomer ternary blends were affected by the cation types (Na^+ or Zn^{2+}) and contents (5–20 wt%) of the added EMA ionomers. The ternary blend containing 20 wt% zinc-neutralized EMA ionomer and 1.0 p.h.r. DCP showed the highest J_c values of the blends. The results have been discussed with regard to the fracture topology observed by scanning electron microscopy (SEM).

1. Introduction

Toughened polymers of multi-phases have been finding increasing utilization in plastic and rubber industries. Among the several toughened polymers are the blends of polypropylene (PP) and ethylene–propylene–diene terpolymers (EPDM) [1–3]. Recently, it was reported that the properties and miscibility of the EPDM and PP blends could be improved by incorporating a small amount of poly(ethylene-co-methacrylic acid) (EMA) ionomers, in which the EMA copolymers were neutralized with a metal ion such as Na^+ or Zn^{2+} [4]. It might be also expected that the incorporation of a small amount of ionomers into the PP/EDPM blend could exhibit improved toughness, because the ethylene-base ionomers themselves were known to possess high toughness. However, limited fracture and toughness data are available for these important industrial polymers. The PP/EPDM blends were sometimes prepared in an intensive mixer by the "dynamic vulcanization" method where EPDM was vulcanized under shear with peroxide. The dynamically vulcanized blends have important technical advantages in processing because of the thermoplastic nature of the melt, even though they contain a cross-linked elastomer as one component [5, 6]. It was found that such thermoplastic nature of the blends might be ascribed to the dynamic aspects of curing, preventing the formation of three-dimensional infinite network in the elastomer phase.

The fracture toughness characterization of polymers has always followed the lead of metals characterization. Thus, when the requirements of linear elastic fracture mechanics could not be satisfied for ductile and toughened polymers, interest moved from fracture toughness characterization, based on the stress intensity factor, *K*, to the *J*-integral concept introduced by Rice or Bagley and Landes [7–9]. In the ASTM standard for *J*-integral characterization, the *J*-integral value at crack initiation, J_{int}, is specified as the intrinsic fracture toughness value. There have been several efforts to determine the J_{int} values for ductile or impact-modified polymers, even though the reported methodology has been very controversial.

Recently, a novel test technique has been developed by Kim and Joe [10, 11] in which a fracture test was carried out using simple single-edge notched (SEN) tensile specimens. The technique is based on the locus of crack initiation points on load–displacement records. It was reported that the evaluation method of J_c was successfully applied to highly deformable materials including a thermoplastic elastomer like Santoprene, without restricting the ratio of the initial crack length to the specimen width (a/w) or the specimen length, provided that the locus line can be located on the load–displacement record [12]. The locus method is believed to be suitable for our PP/EPDM/ionomer systems, because the present work deals with a very similar material as used for their work.

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TABLE I Materials and their characteristics

Material	Properties	Source
PP	$M_n = 2.83 \times 10^4$ $M_W = 2.02 \times 10^5$ $MFI^a = 6.0$ $M_W/M_n = 7.14$	Korea Petrochemical Co. Ltd. (PP4017)
EPDM	η_{inh} $(dl\,g^{-1})^b = 1.22$ $I.V.^c = 15.2$ $PE/PP\ (mol\ \%)^d = 52.0/48.0$ ENB type	Uniroyal (Roy. 521)
Ionomer A	Cation type: Na^+ Ethylene/methacrylic acid = 91/9 % Neutralization: 50% Sp.gr = 0.94 $MFI^a = 1.3$	Du Pont (Surlyn 8528)
Ionomer B	Cation type: Zn^{2+} Ethylene/methacrylic Acid = 91/9 % Neutralization: 50% Sp.gr = 0.95 $MFI^a = 1.1$	Du Pont (Surlyn 9520)
DCP	Granule type	Mitsui Chemical Co.

[a] Melt flow index.
[b] $0.5\ g\,dl^{-1}$ xylene solution at 70 °C.
[c] By the ICI titration method.
[d] By IR analysis.

The objective of the study was, therefore, to investigate the fracture toughness of the dynamically vulcanized EPDM and PP/ionomer ternary blends and especially to analyse the effect of ionomer addition on the fracture behaviour of the dynamically vulcanized EPDM and PP binary blends. In the present investigation, two kinds of poly(ethylene-co-methacrylic acid) ionomers containing different metal ions (Na^+ or Zn^{2+}) were used for comparison, and the effects of the metal component for neutralization in the ionomer and the ionomer contents in the PP/EPDM blend were discussed. The composition of the blend was fixed at 50/50 PP/EPDM by weight. The ionomer contents added to the PP/EPDM blend varied from 5–20 wt %.

2. Experimental procedure

2.1. Materials

Table I summarizes the characteristics of the polymers used in this study. The polypropylene (PP) used in this work was a Korea Petrochemical PP4017. The ethylene–propylene–diene terpolymer (EPDM) with ethylidene-2-norbornene (ENB) as a termonomer was Royalene 521 supplied by Uniroyal (weight average molecular weight ($M_w = 1.80 \times 10^5$; ethylene content, $C_2 = 52$ mol %). The polymers were used as-received. Two kinds of EMA ionomers were supplied from Dupont. The ionomers were dried at 63 °C under vacuum for 76 h before use. The polymers were vulcanized with two different concentrations (0.33 and 1.0 p.h.r.) of dicumyl peroxide (DCP). The dynamically vulcanized EPDM and PP binary or PP/EPDM/ionomer ternary blends have been prepared in a Brabender Roller Mixer (Type w50H) as follows. The EPDM and peroxide were preblended in a 3 in × 7 in (~7.6 cm × 17.8 cm) research mill (Farrel Co.) at a roll temperature of 80 °C for 10 min. The roll-milled strands of EPDM-DCP mixture were blended with PP or PP/ionomer mixture in the Roller Mixer at 190 °C for 15 min. The EPDM was dynamically vulcanized under shear in the presence of PP or PP/ionomer mixture. During the experimental runs, the shear intensity was controlled by adjusting the rotating speed of the mixer to 60 r.p.m. The composition of PP and EPDM was fixed at a 50/50 by weight. For the ternary blends, the ionomer contents were varied from 5–20 wt % based on the total amount of PP and EPDM. The sample notations of blends are summarized in Table II.

2.2. Fracture energy determination

Many different specimen configurations are acceptable for the measurement of fracture toughness. We used single-edge notched (SEN) tensile specimens with a constant length from compression-moulded sheets. The thickness and width of the specimens were 1.0 and 20.0 mm, respectively. The length between the grips were 60.0 mm. Razor blades were used to create sharp initial cracks, which varied from 0.20–0.80 in terms of the ratio of the initial crack length, a, to the specimen width, w. Tensile tests were performed at a cross head speed of $50\ mm\,min^{-1}$ with an ambient temperature of 26 °C and relative humidity of 35%. Load–displacement graphs were recorded and initiation points were marked on each loading line during the test. The fracture toughness was interpreted in terms of the critical J-integral value, J_c, by the locus method developed by Kim and Joe [10, 11].

TABLE II Blended materials and their compositions

Notation	PP contents (wt %)	EPDM contents (wt %)	Ionomer contents (wt %)	DCP concentration (p.h.r.)
PP50-0.33DEP50	50.0	50.0	0.0	0.33
PP50-0.33DEP50/IA5	47.5	47.5	5.0	0.33
PP50-0.33DEP50/IA10	45.0	45.0	10.0	0.33
PP50-0.33DEP50/IA15	42.5	42.5	15.0	0.33
PP50-0.33DEP50/IA20	40.0	40.0	20.0	0.33
PP50-0.33DEP50/IB5	47.5	47.5	5.0	0.33
PP50-0.33DEP50/IB10	45.0	45.0	10.0	0.33
PP50-0.33DEP50/IB15	42.5	42.5	15.0	0.33
PP50-0.33DEP50/IB20	40.0	40.0	20.0	0.33
PP50-1.0DEP50	50.0	50.0	0.0	1.00
PP50-1.0DEP50/IA5	47.5	47.5	5.0	1.00
PP50-1.0DEP50/IA10	45.0	45.0	10.0	1.00
PP50-1.0DEP50/IA15	42.5	42.5	15.0	1.00
PP50-1.0DEP50/IA20	40.0	40.0	20.0	1.00
PP50-1.0DEP50/IB5	47.5	47.5	5.0	1.00
PP50-1.0DEP50/IB10	45.0	45.0	10.0	1.00
PP50-1.0DEP50/IB15	42.5	42.5	15.0	1.00
PP50-1.0DEP50/IB20	40.0	40.0	20.0	1.00

It was reported that the locus method using a tensile specimen was successfully applied to the Santoprene-like highly deformable materials when compared to the conventional method using a three-point bend specimen [13, 14]. Crack initiation points were easily observable because the crack opened widely before it propagated. The areas under the loading curves were calculated numerically from the data points taken from the load–displacement records. The essential energy needed for crack propagation per unit thickness, ΔU_c versus the initial crack length, a, was plotted. The linear least-squares fitted slope was taken as J_c.

The method determines J_c based on

$$J_c = \frac{-1}{B}\frac{\Delta U_c}{\Delta a} \tag{1}$$

where B is the thickness of the specimen, a is the initial crack length and U_c is the enclosed area between loading line and the locus line. The total energy consumed during fracture testing includes some amount of remote energy loss as well as the energy supplied for the crack propagation. Remote plastic energy loss occurs during the loading process if plastic deformation, remote from the crack tip, exists. Several single specimen test methods which use the relation between the essential energy, U_c, and the total energy absorbed, U_T, have been developed [11]. The value of $\phi(= U_c/U_T)$ was known to be sensitive to the remote energy absorption. With the J_c value known, ϕ for each crack size can be determined from Equation 2

$$\phi = \frac{J_c}{[U_T/B(w - a)]} \tag{2}$$

If the crack initiation has occurred at a constant displacement and the locus of the crack initiation points continued to be a vertical line down to the displacement axis, then all the ϕ values should have been 1. It was reported that the remote energy absorption can affect the accuracy of the experimentally determined J_c values and that eliminating the remote energy term in the early stage of the procedure can help to yield consistent J_c values [10]. Details of the locus method are described elsewhere [10–12].

The reproducibility of the fracture energy data was measured by testing different sample lengths. However, all samples were tested with the initial sample length of 100 mm unless otherwise specified. Examination of the fractured surfaces was made using a scanning electron microscope (SEM; Jeol JSM-35CF).

3. Results and discussion

3.1. J_c values

Fig. 1 shows typical load–displacement records for the dynamically vulcanized EPDM and PP binary blend (DCP content 0.33 p.h.r.). The bars denote the spread of observed crack initiation points. The locus line slightly deviates from a vertical line.

ΔU_c per unit thickness was plotted against each initial crack size for the dynamically vulcanized EPDM and PP binary or EPDM and PP/ionomer ternary blends to obtain the J_c values. Fig. 2 shows a typical result when the DCP content was 1.0 p.h.r. and the used ionomer was zinc-neutralized ionomer B. The slope of the least-square-fitted line yields J_c, and the resulting values are replotted against ionomer content in Fig. 3.

The average correlation coefficient of the J_c test was 0.95. It is seen that linear relationships between U_c and a have been obtained for both binary and ternary blends. The result implies that the J value at the crack initiation point, J_c, is a constant for a given thickness, which is the only assumption made in the locus method and proves the validity for our blend system.

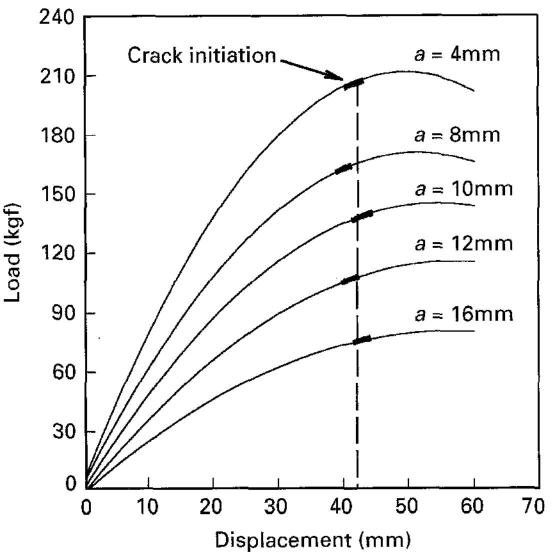

Figure 1 Typical load–displacement curves for the dynamically vulcanized EPDM and PP binary blend (DCP content = 0.33 p.h.r.): the spread bars denote the region of crack initiation points.

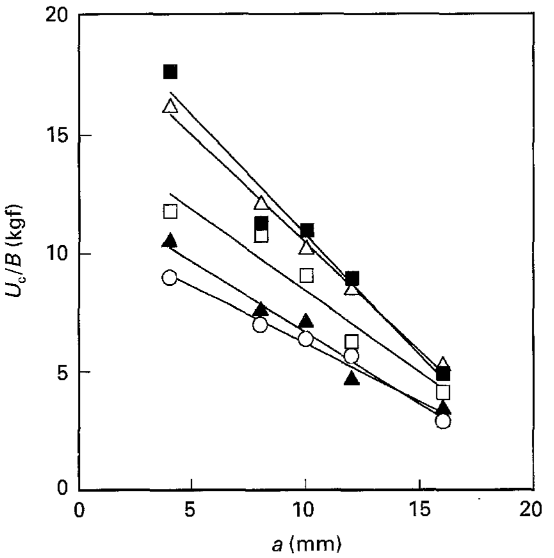

Figure 2 Variation of essential energy needed for crack initiation per unit thickness (U_c/B) with initial crack size, a, in the ternary blends composed of PP, highly vulcanized EPDM and ionomer B (PP50-1.0DEP50/IB). Least-squared fit. Ionomer B (wt %): (▲) 0, (○) 5, (△) 10, (□) 15, (■) 20.

In Fig. 4, it is shown that when the DCP content was low (0.33 p.h.r.) the J_c values of the dynamically vulcanized EPDM and PP binary blend were reduced by adding ionomers, irrespective of the ionomer types. The result means that the incorporation of ionomer sacrifices the toughness of the PP/EPDM binary blend when the blends were lightly vulcanized with low DCP content, even under shear.

The result may be due to the phase separation of cross-linked EPDM and PP, and the addition of ionomers was not helpful to compatibilize PP and cross-linked EPDM. Even though the reduction in fracture toughness seemed to be more clearly observed for the dynamically vulcanized EPDM and PP/zinc-neutralized ionomer B ternary blends, the difference of ionomer types is within the experimental errors and did not affect the J_c values. For the dynamically vulcanized EPDM and PP/ionomer blends with a DCP content of 1.0 p.h.r., however, different J_c behaviours were observed against ionomer contents depending on the ionomer types, as shown in Fig. 3. The J_c values of the dynamically vulcanized EPDM and PP binary blends were generally increased with increasing ionomer contents in the case of zinc-neutralized ionomer B, whereas they were not significantly changed by the addition of the sodium-neutralized ionomer A. The results of Figs 3 and 4 suggest two important facts. (1) When the DCP content is low, i.e. the blends contain lightly cross-linked rubber (EPDM here) phase, the multiphasic behaviour in the blends yields poor fracture toughness. When the DCP content is high, i.e. the blends contain highly cross-linked rubber phase through the dynamic vulcanization, the dynamically vulcanized blends exhibit the enhanced

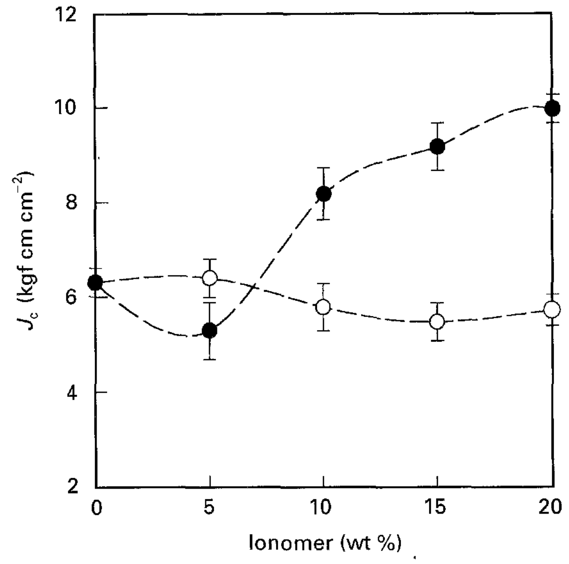

Figure 3 Effect of the added ionomer on the fracture energy, J_c, in highly vulcanized ternary blends: (○) PP50-1.0DEP50/IA, (●) PP50-1.0DEP50/IB.

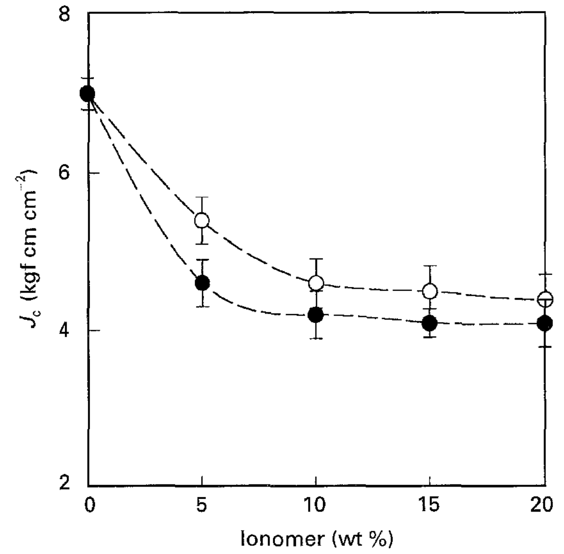

Figure 4 Effect of the added ionomer on the fracture energy J_c in lightly vulcanized ternary blends: (○) PP50-0.33DEP50/IA, (●) PP50-0.33DEP50/IB.

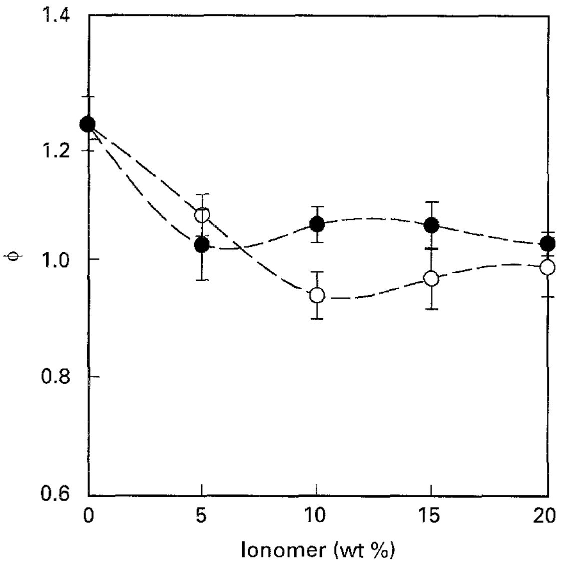

Figure 5 Effect of the added ionomer on the ratio, ϕ, of essential crack initiation energy to total energy needed for crack initiation in lightly vulcanized ternary blends: (○) PP50-0.33DEP50/IA, (●) PP50-0.33DEP50/IB.

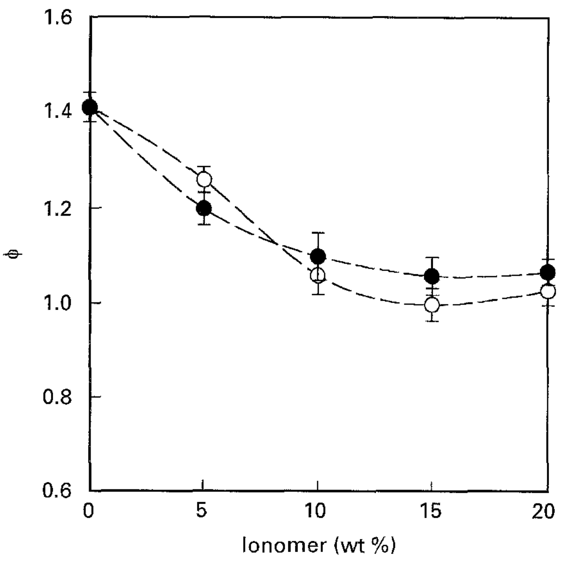

Figure 6 Effect of the added ionomer on the ratio, ϕ, of essential crack initiation energy to total energy needed for crack initiation in highly vulcanized ternary blends: (○) PP50-1.0DEP50/IA, (●) PP50-1.0DEP50/IB.

fracture toughness. (2) For the dynamically vulcanized EPDM and PP/ionomer ternary blends with high DCP content, the improvement of fracture toughness of the dynamically vulcanized EPDM and PP binary blend by the incorporation of ionomer is more significantly observed in the case of zinc-neutralized ionomer B than in the case of sodium-neutralized ionomer A. The result may be due to the development of a well-defined thermoplastic interpenetrating polymer network (IPN) structure for the dynamically vulcanized EPDM and PP/zinc-neutralized ionomer B. Although the sodium-neutralized ionomer A can form an IPN between PP and EPDM, the possibility is reported to be less than that of zinc-neutralized ionomer B because of the monovalent nature of Na^+ [15].

3.2. Remote energy absorption

The total energy consumed during fracture testing includes some amount of remote energy loss as well as the energy supplied for the crack propagation. The remote energy absorption away from the crack tip is not negligible if the specimen length is not long [11]. In this work, the specimen length is 100 mm. The remote energy absorption in determining the J_c value was also evaluated.

Fig. 5 shows the effect of the ionomer addition on the ϕ values. In this plot, the ϕ value for the initial crack in length (a/w) of 0.5 was compared. The ϕ value for the dynamically vulcanized EPDM and PP binary blend with low DCP content was slightly higher than 1.0, but those for the ternary blends were equal to or slightly less than 1.0, regardless of ionomer types and contents. The result implies that the effect of remote energy absorption is negligible for both the ionomer-added ternary blends and the PP/EPDM binary blend and the effect needs not to be taken into account to estimate J_c values from our locus method for the dynamically vulcanized EPDM and PP/ionomer ternary blend as well as the binary blend when the DCP content is low. It should be noted that the remote energy absorption for the dynamically vulcanized EPDM and PP/ionomer ternary blends is much smaller as compared with the dynamically vulcanized EPDM and PP binary blend. The ϕ values for the ternary blends having zinc-neutralized ionomer B are slightly larger than those ternary blends containing sodium-neutralized ionomer A. This trend was due to the fact that the crack initiation locus below the loading curve of the largest crack size has a negative slope in the load–displacement record, meaning that the critical displacements (crack initiation displacements) are larger at the same initial crack length. The trend of ϕ values implies that even though the J_c values determined by the locus method for the ionomer A-containing ternary blends are more accurate than the ionomer B-containing ternary blends, the significance is not large, and thus the J_c values for ionomer B-containing ternary blends are also acceptable in our work.

Fig. 6 shows the ϕ values of the dynamically vulcanized EPDM and PP/ionomer ternary blend as well as EPDM and PP binary blend with high DCP content. In this plot, the ϕ value for the initial crack of length $(a/w) = 0.5$ was also compared. The ϕ values for the dynamically vulcanized EPDM and PP/ionomer ternary blend with high DCP content were also slightly higher than 1.0, regardless of ionomer types. The result means that the effect of remote energy absorption is also negligible for the ionomer-added ternary blends, even when the DCP content is high, although the effect is significant for the dynamically vulcanized EPDM and PP binary blend and the ternary blend containing 5 wt % of ionomers when the DCP content is high. Comparison of Figs 5 and 6 indicates that the ϕ values approach unity as the ionomer contents increase, regardless of ionomer types and DCP contents. The result suggests that the J_c values determined by the locus method for the dynamically vulcanized

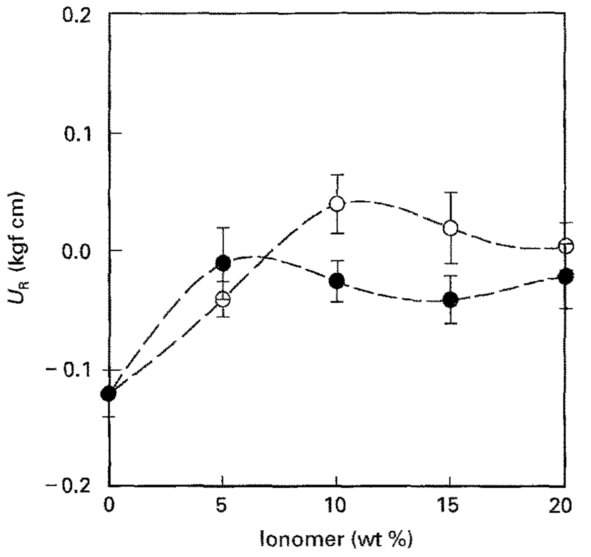

Figure 7 Effect of the added ionomer on the remote or plastic deformation energy, U_R, in lightly vulcanized ternary blends: (○) PP50-0.33DEP50/IA, (●) PP50-0.33DEP50/IB.

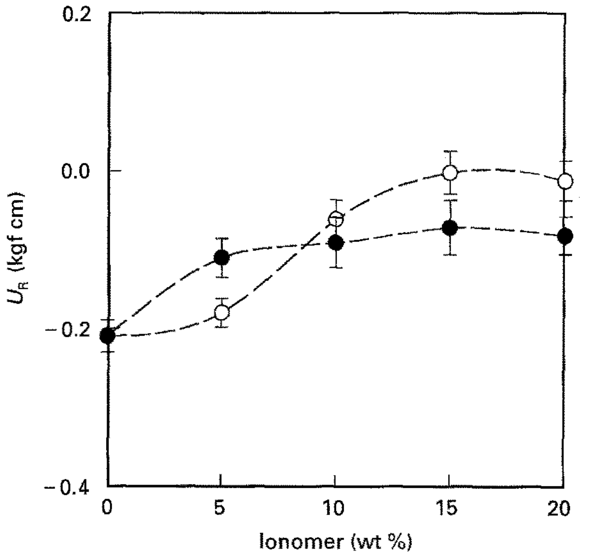

Figure 8 Effect of the added ionomer on the remote or plastic deformation energy, U_R, in highly vulcanized ternary blends: (○) PP50-1.0DEP50/IA, (●) PP50-1.0DEP50/IB.

TABLE III Fracture energy of dynamically vulcanized EPDM and PP binary or dynamically vulcanized EPDM and PP/ionomer ternary blends

Sample	Fracture energy, J_c (kgf cm cm^{-2})
PP	2.90
PP50-0.33DEP50	7.00
PP50-0.33DEP50/IA5	5.40
PP50-0.33DEP50/IA10	4.30
PP50-0.33DEP50/IA15	4.50
PP50-0.33DEP50/IA20	4.40
PP50-0.33DEP50/IB5	4.60
PP50-0.33DEP50/IB10	4.50
PP50-0.33DEP50/IB15	3.80
PP50-0.33DEP50/IB20	4.10
PP50-1.0DEP50	6.30
PP50-1.0DEP50/IA5	6.40
PP50-1.0DEP50/IA10	5.80
PP50-1.0DEP50/IA15	5.50
PP50-1.0DEP50/IA20	5.75
PP50-1.0DEP50/IB5	5.30
PP50-1.0DEP50/IB10	8.20
PP50-1.0DEP50/IB15	9.20
PP50-1.0DEP50/IB20	10.00

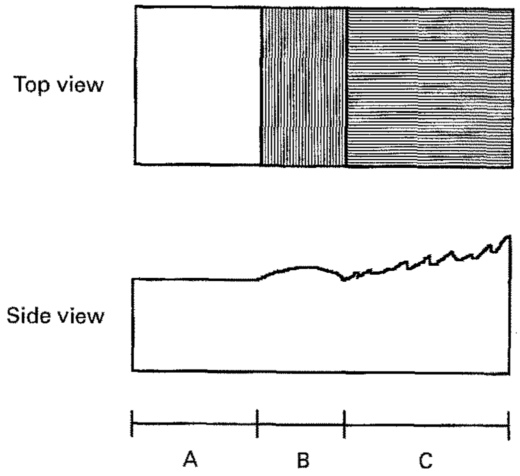

Figure 9 Schematic diagram of a fractured specimen from top and side view. A, B and C are a notched region, an initiation region (stretched zone) and end band region (rapidly destroyed region), respectively.

blends having higher ionomer contents, are more accurate than for the ternary blend having lower ionomer contents, as well as the PP/EPDM binary blend, irrespective of ionomer types.

Plots of remote absorption energy, U_R, against the ionomer content, as shown in Figs 7 and 8, also show the same trend as referred to in Figs 5 and 6. The general trend of U_R approaching 0.0 is more clearly observed for the ternary blends as the ionomer contents increase; i.e. the effect of remote energy absorption is not significant ($U_R \approx 0.0$) for both the dynamically vulcanized EPDM/PP/ionomer ternary blends, regardless of DCP contents as well as ionomer types, whereas it is not negligible for the dynamically vulcanized EPDM and PP binary blend irrespective of the DCP contents.

Table III shows the fracture energy data for all the blend samples investigated. It should be noted that all of the J_c values of the dynamically vulcanized EPDM and PP binary and PP/ionomer ternary blends are larger than that of PP. The result implies that the incorporation of ionomer and the dynamic vulcanization enhance the toughness of PP. As explained in Figs 3 and 4, of importance is that the dynamically vulcanized EPDM and PP/zinc-neutralized ionomer B with high DCP content exhibited generally high J_c values, i.e. good fracture toughness.

3.3. Fracture surface topology

In our previous work, the PP/EPDM/ionomer ternary blends showed very complicated multiphasic morphologies [4]. The fracture surface topology was observed by scanning electron microscopy. The scanning electron micrograph of Fig. 9 shows the majority

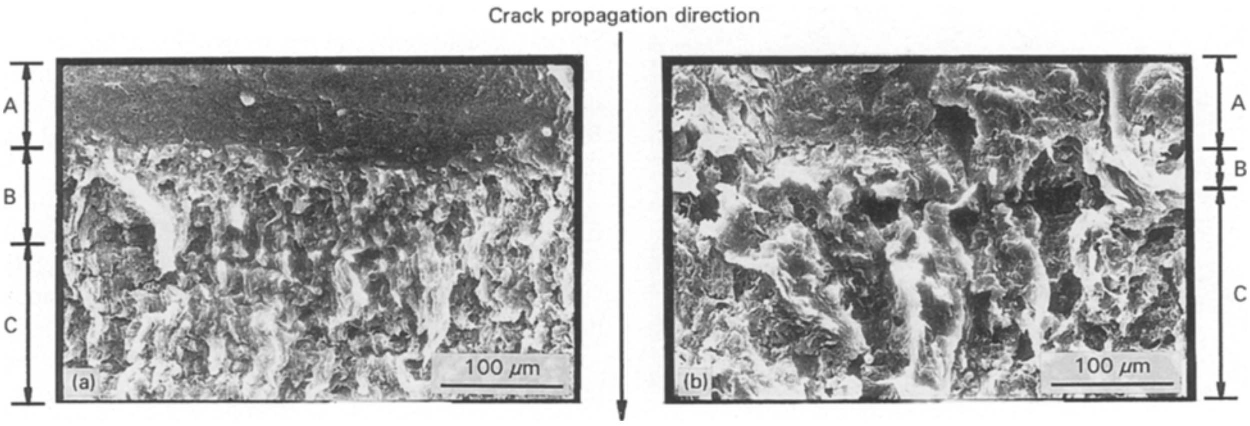

Figure 10 SEM microfractographs of dynamically vulcanized EPDM binary blends at a magnification of × 300: (a) PP50-0.33DEP50, and (b) PP50-1.0DEP50. The initial crack length was 8 mm. A, B and C are the same as in Fig. 9.

of the fractured surface of the dynamically vulcanized blends. In these micrographs, A, B and C represent the initial crack tip, initiation region and end band region, respectively. The direction of crack travel is from top to bottom. When the samples with an initial crack are subjected to load, they initially resist crack propagation, but on exposure to a high load, they finally undergo spontaneous failure. When a material is tough enough to resist the crack propagation, the material will stretch over long distances until it reaches failure. We call the distances between the initial crack region and end band region, the initiation region.

Typical top views of fractured samples are shown in Fig. 10 for the dynamically vulcanized EPDM and PP binary blends with both high and low DCP content. The dynamically vulcanized EPDM and PP binary blends showed somewhat quasi-cleavage fracture topology [16], regardless of the DCP contents. Fig. 11 shows scanning electron micrographs of the fractured surfaces taken around the crack-tip for the dynamically vulcanized EPDM and PP/ionomer ternary blends having 20 wt % ionomers when the DCP content is low. In this case the initial crack length was 8 mm. The ionomer-added ternary blend shows no clear fracture surface topology of tough materials even the ionomer contents are 20 wt %, regardless of ionomer types. The ionomer-added ternary blends with high DCP content, however, showed slightly different fracture surface topologies.

In Fig. 12, scanning electron micrographs of the fractured surfaces taken around the crack-tip are shown for the 5 and 20 wt % ionomer-added dynamically vulcanized ternary blends when the DCP content is high. In this case, the initial crack length was 8 mm. The ionomer-added ternary blends show typical fracture surface topology of tough materials irrespective of ionomer types and the trend is clearer when ionomer contents are higher. The micrographs reveal well dimple-ruptured topologies, which are usually observed in tough materials. Careful inspection of Fig. 12a–d shows that the fracture surface of 20 wt % zinc-neutralized ionomer B-added dynamically vulcanized ternary blends has most clear dimple fracture topology, exhibiting the toughest characteristics among the blends. The result is closely related to the highest J_c values of the same material.

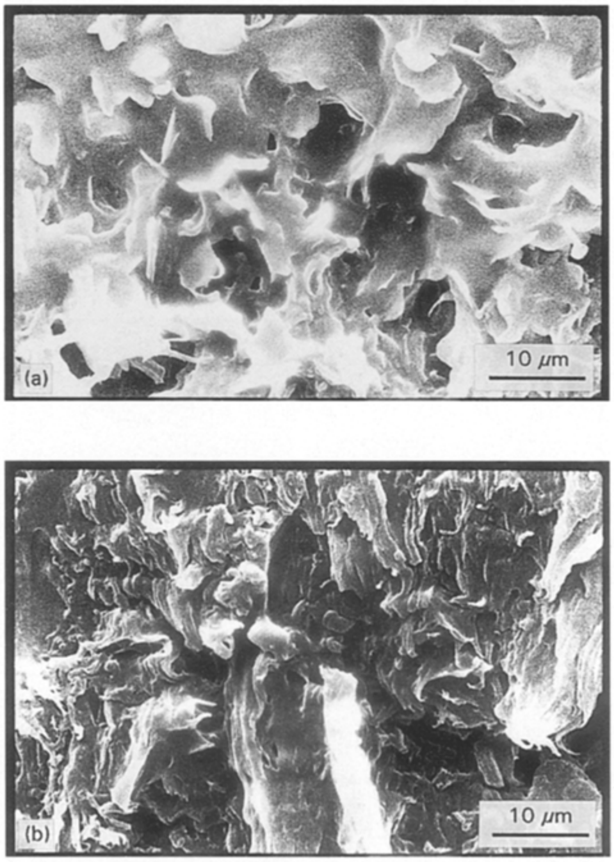

Figure 11 SEM microfractographs of lightly vulcanized ternary blends: (a) PP50-0.33DEP50/IA20 and (b) PP50-0.33DEP50/IB20. The initial crack length was 8 mm.

The result in Fig. 12 may be ascribed to the structural features of the thermoplastic IPN in the case of the blends, as already explained in Fig. 4. From this fracture topology with the J_c behaviour, one can conclude that the application of dynamic vulcanization and the addition of ionomer played a synergistic role to enhance the fracture toughness of PP or PP/EPDM blend.

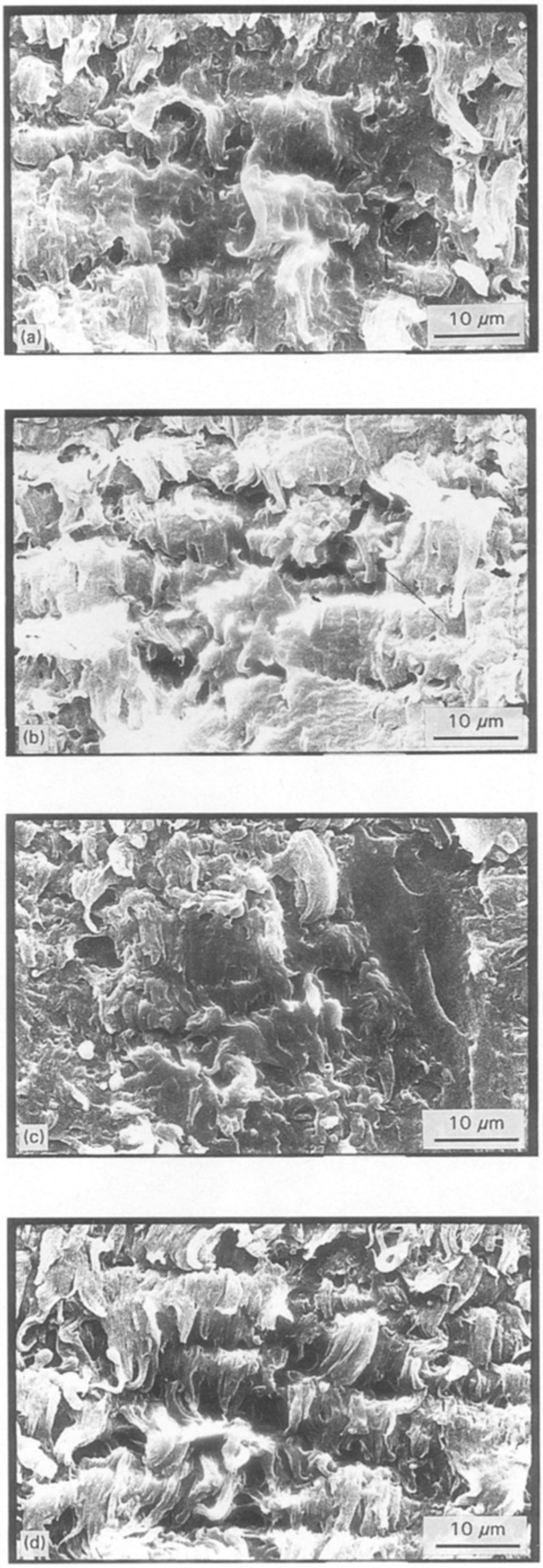

Figure 12 SEM microfractographs of highly vulcanized ternary blends: (a) PP50-1.0DEP50/IA5, (b) PP50-1.0DEP50/IA20, (c) PP50-1.0DEP50/IB5, and (d) PP50-1.0DEP50/IB20. The initial crack length was 8 mm.

4. Conclusions

Several conclusions can be drawn from the above results concerning the fracture mechanics investigation on the dynamically vulcanized EPDM and PP/ionomer ternary blends by using the J_c integral via the locus method.

1. The ionomer-added dynamically vulcanized EPDM and PP/ionomer blends with low DCP content showed lower J_c values than the dynamically vulcanized EPDM and PP binary blend but much higher than that of PP itself.

2. The J_c values became much higher for the ternary blends containing more than 10 wt % zinc-neutralized ionomer when they are dynamically vulcanized with high DCP content.

3. The ternary blend containing an ionomer showed negligible remote absorption energy, which manifests the validity of the evaluation of J_c values by the locus method. It can be concluded that the incorporation of a small amount of ionomer and the application of dynamic vulcanization increased J_c values, enhancing the fracture toughness of dynamically vulcanized EPDM and PP blend. The dynamically vulcanized blend using 20 wt % zinc-neutralized ionomer with high DCP content showed the most prominent enhancing effect, plausibly due to the thermoplastic IPN structural feature. Note also that the evaluation of J_c integrals, by using a simple single-edge notched specimen, was successfully applied to investigate the fracture behaviour of the dynamically vulcanized EPDM and PP/ionomer ternary blends.

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